The new cryogenic vacuum chamber and blackbody source for infrared calibrations at NIST's FARCAL facility

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Abstract

The Facility for Advanced Radiometric Calibrations (FARCAL) at the National Institute of Standards and Technology (NIST) in Gaithersburg, MD is comprised of the Medium Background Infrared (MBIR) facility and the Training for Calibration Expertise in Radiometry (TraCER); the latter being a classroom setting. The MBIR is a 120 cm by 180 cm vacuum chamber with an internal cold shroud and an integral rollout table. The chamber will contain a blackbody source and an absolute cryogenic radiometer (ACR). Both components are mounted on the rollout table. Measurements will be performed in the MBIR facility that cannot be accomplished using existing facilities, including the NIST Low Background Infrared (LBIR) facility and the room

temperature non-vacuum radiometric facilities. Initially the MBIR facility will be used for 80 K medium background measurements and 300 K ambient background measurements.

1. Introduction

The Facility for Advanced Radiometric Calibrations (FARCAL) at the National Institute of Standards and Technology (NIST), consists of the Medium Background Infrared (MBIR) facility and the Training for Calibration Expertise in Radiometry (TraCER) classroom. TraCER will be used for instructional courses, workshops, and general meetings pertaining to thermal radiometry and other related items. The FARCAL facility is housed in the high bay area depicted in Fig. 1, located in the Radiation Physics building at NIST at the sub-basement level. Substantial renovation was required to this decommissioned nuclear physics facility to accommodate the chamber, its associated support equipment, and the classroom. There is also space available for future expansion.

The MBIR facility was constructed to provide radiometric measurement capability in an 80 K environment. Previously, radiometric measurements at NIST were only possible in a 300 K environment in the laboratory or a 20 K environment in the Low Background Infrared (LBIR) facility. NIST traceable calibrations in an 80 K environment are important for many space-based applications. The 80 K environment produces thermal radiation, but is negligible for the purposes of programs which focus on blackbody sources with temperatures between 250 K and 350 K. One of the initial calibrations will be the Thermal Transfer Radiometer (TXR) [1] being developed at NIST in support of the Earth Observing System (EOS). EOS is the key element in the National Aeronautics and Space Administration's (NASA's) Mission to Planet Earth (MTPE) program.

Measurements made in the MBIR facility will be traceable to the absolute cryogenic radiometer in the LBIR facility through a blackbody source. This and other blackbody sources will also be directly calibrated using an internal absolute cryogenic radiometer (ACR) [2] that is under development. Comparisons with other ACRs at NIST, the High Accuracy Absolute Cryogenic Radiometer (HACR) [3] and the ACR at the Syncrotron Ultraviolet Radiation Facility (SURF) [4], could also be performed if necessary.

As an adjunct to the FARCAL facility, there is a classroom setting which contains the necessary space and equipment for classroom instruction in radiation temperature measurement theory and technique. In the past, there have been many problems in thermal radiometric measurements related to the use of improper techniques and assumptions. NIST has recently presented a course at this classroom facility, which was designed to illustrate the consequences of common assumptions, thereby improving the techniques used in the measurement process. NIST plans to present this course annually in the future.

2. MBIR

The MBIR facility is located in a soft-wall class 10 000 cleanroom. The vacuum chamber, shown in Fig. 1, has a diameter of 120 cm and a length of 180 cm with internal light-tight radiation shrouds which currently are operated at 80 K using liquid nitrogen cooling. Inside the cooled shrouds is a roll-out table, shown in Fig. 2, which will permit large instruments, up to 61 cm high by 91 cm wide, to be accommodated. Active temperature control of the internal components will allow the table temperature to be maintained near 80 K. Ten temperature sensors are attached to the shrouds and the table to permit recording of the temperatures of the various sections of the inside surfaces. The chamber is evacuated using a large oil-free pump and then switched to a cryo-pump. The base pressure is approximately $1.33x10^{-4}$ Pa ($1x10^{-6}$ Torr) without liquid nitrogen in the shrouds. With the shrouds at 80 K, the pressure is approximately $1.33x10^{-5}$ Pa ($1x10^{-7}$ Torr).

All of the physical functions of the chamber, such as pump-down and cooling sequences, will be automated using appropriate computer hardware and a multitasking control program.

Future expansion of the capabilities of the chamber will include variable temperature control of the surface temperatures of the radiation shroud and table by using automated valves to control the flow rate of the working fluid, which can be

liquid, bi-phase or cold nitrogen gas. If necessary, heaters will be added to the shrouds and table. With heaters, the shroud temperature could be controlled from 80 K to 325 K. This would be a very important improvement, as thermal radiometers are sensitive to the thermal environment, adversely affecting the infrared measurement accuracy and precision. The temperature will be set and controlled by the multitasking micro-computer system.

Initially only the large area blackbody source, shown in Fig. 3, will be installed in the calibration chamber. Later, an ACR, shown schematically in Fig. 4, will also be installed as a permanent part of the system. These instruments will be used to calibrate the TXR, a portable infrared transfer radiometer, shown in Fig. 5. The TXR has been developed at NIST and will be calibrated in 1998. The TXR, after characterization and calibration, will allow *in situ* **calibrations of primary standard blackbody sources in thermal vacuum calibration chambers that are a part of NASA's EOS program.**

Future uses of this high vacuum, thermally-controlled chamber may include focal plane array calibrations and standards development including source and detector calibration and characterization. Novel radiometric experiments that would benefit from a stable thermal environment or are comprised of cold components will be implemented as needed. Examples include an infrared beam conjoiner, a spectral comparator, and an infrared polarimeter [5]. Point-spread functions could also be accomplished with the addition of appropriately configured sources.

4. Blackbody Source

The blackbody source shown in Fig. 3 is nearly identical to a source [6] designed by personnel from NIST and the Los Alamos National Laboratory (LANL) in support of a space-based optical sensor. The LANL blackbody source was calibrated in the LBIR facility at NIST, using the LBIR absolute cryogenic radiometer. A special vacuum vessel was attached to the LBIR chamber to accommodate the blackbody source and to permit spatial uniformity measurements of the blackbody cavity. The blackbody has a temperature range of 180 K to 350 K and was recently calibrated at several temperatures within this range.

The blackbody consists of a conical-cylindrical cavity, thick-film heater sections, an actively cooled shroud, and a cold aperture. The cavity has a diameter of 10.4 cm with a 3.17 to 1 length to diameter ratio. It is constructed of aluminum alloy and is coated on the inside with Martin Enhanced Black [7][8]. The calculated cavity emissivity is 0.999 in the 1 μm to 14 μm wavelength range when spectrally averaged over a 9.06° half-angle field-of-view.

The cavity is divided into seven zones, three zones in the conical section, three zones in the cylindrical section and a seventh zone at the exit aperture. Each zone has four platinum resistance thermometers (PRTs) around the outside circumference, equally spaced, and a thick-film heater attached over the outside surface. Each zone is then independently temperature-controlled between 180 K and 350 K. The specially

modified temperature controllers, which permit temperature averaging of the four PRT outputs, compute the average temperature within a given zone and control the zone temperature to the temperature required for that zone. Calculations have been made to determine the optimum temperature profile in each zone to attain an overall temperature variation of 30 mK to 50 mK over the entire cavity. The blackbody will be installed sometime in 1998.

5. ACR

The ACR shown in Fig. 4 is an active cavity type radiometer. The cavity receiver is conical in design with a 1 cm diameter and a 30° apex angle. The inside surface is painted with Z302 [9] specular black paint. There is a wire wound heater and a superconductor temperature sensor, which has a critical temperature (Tc) of 90 K, attached to the cavity. The sensor leads, heater leads and the cavity lip are attached to a cold shell surrounding the cavity that acts as a heatsink for the wires. The entrance to the cavity is fitted with a baffle tube, limiting aperture, and shutter. The ACR will be mounted on the actively-cooled table inside the MBIR chamber and will be operated near 90 K.

The ACR will be used to provide absolute calibrations for sensors and radiometers, including the TXR. Current plans are to intercompare the ACR directly to the HACR, with the ACR inside a portable liquid nitrogen cooled cryostat.

6. Classroom

TraCER is a classroom setting with instructional positions for up to 32 persons when no laboratory session is involved and 16 persons when a laboratory session is required. A Short Course on Temperature Measurement by Radiation Thermometry was held in 1997 and will be repeated annually. The class consisted of 16 students and four experimental stations so each student would have the benefit of close supervision during the laboratory phase.

The four laboratory stations consist of optical tables fitted with sliding rail systems on which are mounted various commercial thermal radiation measurement systems. The sensors face three radiation sources, two commercial blackbodies and a multi-sample flat plate radiator designed and built at NIST. The commercial instruments were on loan through the courtesy and cooperation of the American Society for Testing and Materials (ASTM). The flat plate radiator is designed to demonstrate the emissivity effects of the coatings and oxides which might be present on real surfaces which require temperature measurement.

7. Conclusion

The FARCAL facility includes the MBIR and TraCER, and complements and extends the capabilities of NIST in the measurement of optical radiation. The MBIR facility will provide a new NIST thermal radiation measurement capability with a

thermal background of approximately 80 K with possible future extension to temperatures up to 325 K. This facility will extend the measurement capabilities of the existing NIST thermal infrared facilities. The TraCER facility is a unique, laboratory based teaching environment that provides training in optical radiation measurements under the guidance of NIST metrology experts.

Acknowledgments

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References

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3. Gentile, T. R., Houston, J. M., Hardis, J. E., Cromer, C. L., Parr, A. C., *Appl. Optics* 1996, **35** , 1056-1068.
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5. Russell Chipman, University of Alabama by personal communication.

6. Byrd, D. A., Bender, S. C., Luettgen, A. L., Holland, R. F., Atkins, W. H., *Proc. SPIE*, 1997, **27**

7. Martin Enhanced Black is a proprietary process applied at Lockheed-Martin Aerospace.

8. References are made to certain materials and products in this paper to adequately specify experimental procedures involved. Such identifcation does not imply recommendation or endorsement by the National Institute of Standards and Technology, nor does it imply that the use of these products are necessarily the best for the purpose specified.

9. Lord Corporation Industrial Coatings.

Figure Captions

1. Floor plan of the 1,100 m^2 FARCAL facility showing the Medium Background Infrared calibration facility (MBIR) and the Training for Calibration Expertise in Radiometry classroom (TraCER) facility.

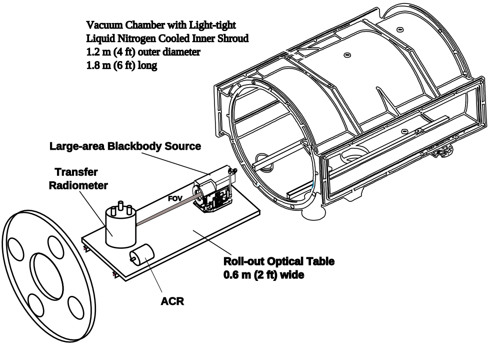
2. Schematic of the environmental chamber showing the vacuum vessel and the roll-out table with the blackbody source, absolute cryogenic radiometer, and transfer radiometer.

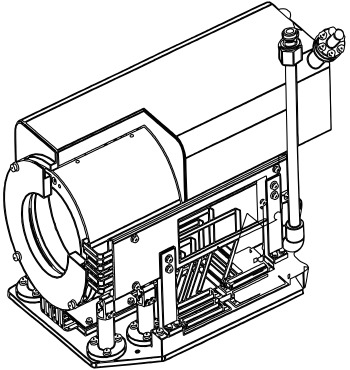
3. Schematic of the internal blackbody source showing a view of the blackbody cavity through the cold shroud of the cavity. The blackbody will be used to transfer calibrations to other devices.

4. Schematic of the absolute cryogenic radiometer, the primary standard for calibration of the blackbody source. The YBCO sensor is made from the high temperature superconductor $Y\ Ba_2\ Cu_3\ O_{7-\delta}$.

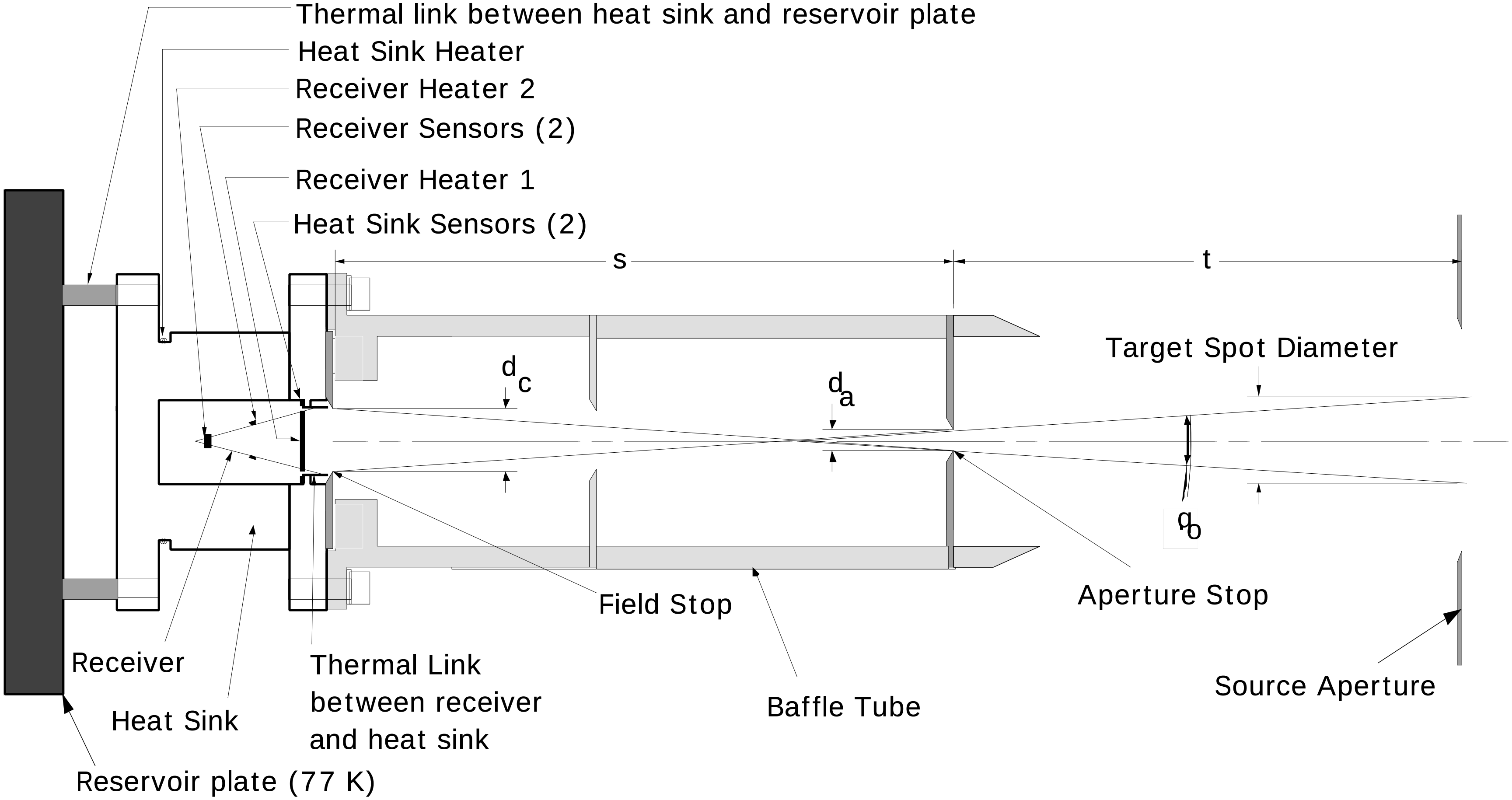
5. Schematic of the thermal transfer radiometer (TXR) to be used for transfer of radiometric calibrations from NIST to instruments in other environmentally controlled vacuum chambers.

Floor plan is an AutoCAD file. Will be included in this PDF in next version.


Vacuum Chamber with Light-tight
Liquid Nitrogen Cooled Inner Shroud
1.2 m (4 ft) outer diameter
1.8 m (6 ft) long
Large-area Blackbody Source
Transfer
Radiometer
FOV
Roll-out Optical Table
0.6 m (2 ft) wide
ACR



MBIR ACR Design



TXR Optical Layout